LCA Case Studies

A Method to Calculate the Cumulative Energy Demand (CED) of Lignite Extraction

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Abstract. For the utilisation of an energy carrier such as lignite, the whole life cycle including necessary energy supply processes have to be considered. Therefore using the 'Cumulative Energy Demand' (CED) is especially suited to determine and compare the energy intensity of processes.
The goal of the CED is to calculate the total primary energy input for the generation of a product, taking into account the pertinent front-end process chains. So the CED is in many steps similar to the LCA, especially in the 'inventory analysis step'. The statements of the CED for energy supply-systems are concerned with the (primary) energy-efficiency of the energy supply and pointing out the life cycle steps with high energy-resources demand. Due to the great environmental impacts of energy supply and use which have to be laboriously assessed in LCA, the CED provides a useful, additional, energy-related 'screening-indicator' to LCA.
This case study analyses the extraction of lignite in an opencast mine in West-Germany as the first step of energy carrier provision. Our data for the inventory analysis arise from a measuring campaign about the period of one year. The results underline the great energy demand of lignite extraction in West-Germany.
With reference to the energy contents of lignite, the fraction of primary energy demands for its' mining amounts to about 6.2%. This accounts to 93.8% of the lignite energy content being available as usable energy for further processes, which is obviously worse than other studies have shown.

Keywords: CED; Cumulative Energy Demand (CED); energy analysis; Life Cycle Impact Assessment; life cycle inventory analysis; lignite; overall efficiency of supply

Introduction

In 1997, the Collaborative Research Center 525 entitled 'Resource-Orientated Integrated Analysis of Metallic Raw Material Flows', funded by the Deutsche Forschungsgemeinschaft (DFG), was established at the Aachen University of Technology (RWTH). This program aims to develop tools for a resource-sensitive utilisation of metallic raw materials covering economic, environmental and social constraints.

To this purpose, nine institutes of the Aachen University of Technology (RWTH) and the Forschungszentrum Jülich are in co-operation. Each of the nine sub-programs of the Collaborative Research Center, shown in **Fig. 1**, contributes to the development of a tool for shaping material flows with their own submodels.

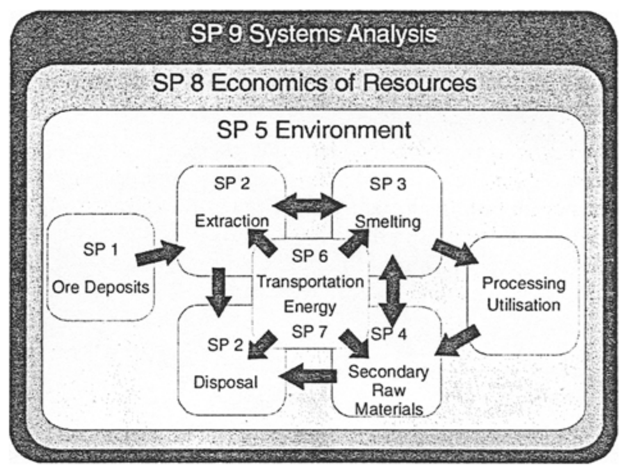

Fig. 1: Structure of the Collaborative Research Center 525

Here, the co-operation of the sub-programs 'Extraction and Disposal' and 'Energy' of the Collaborative Research Center 525 is shown in the field of determining the CED for the supply of lignite.

1 Method of Investigation

1.1 The concept of the cumulative energy demand

The life cycle of a product can generally be subdivided into the three phases of 'production' (P), 'use' (U) and 'disposal' (D) in which final energies, e.g. electricity or fuel, are engaged.

Beside the direct energy input for production, use and disposal of a product, production facilities, as well as raw materials, auxiliary materials and consumables are also used. These are products which need energy for their own production pro-

cess. Furthermore, the final energy applied in the processes is a product of mining, transformation and transport processes which again are performed using machines and consuming different energy carriers and materials.

The question of the energy expenditure for the energy supply is answered by determining the necessary amount of primary energy. The total of all energy inputs, concerning the consumption of primary energy, is called the Cumulative Energy Demand of a product [1].

With respect to the three life phases (production, use and disposal), the CED can be expressed as:

$$CED = CED_P + CED_U + CED_D \tag{1}$$

The Cumulative Energy Demand is a parameter which forms the basis for further energetic assessment values (like energy pay-back time or amortisation time). Of special significance is the overall efficiency of supply.

1.2 The overall efficiency of supply

Many processes require different final energies, e.g. fossil fuels, process steam and electricity. These energies have different physical qualities and thermodynamic properties, for example, it is not suitable to compare 1 MJ of electricity with 1 MJ of low-temperature heat. Therefore, the question of energy demand cannot be answered adequately by simply summing up the final energies which are employed in a process.

However, it is possible to determine the required primary energies from the different final energies using the overall efficiency of supply, which means that the comparison of processes becomes possible. The overall efficiency of supply g describes the relation of the final energy provided and the Cumulative (primary) Energy Demand.

$$g_{el} = \frac{W_{el}}{m_{fuel}^{prim} \cdot H_u^{prim} + \sum_i CED_{plant,i}} \tag{2}$$

$$g_{fuel} = \frac{m_{fuel} \cdot H_u}{m_{fuel}^{prim} \cdot H_u^{prim} + \sum_i CED_{plant,i}} \tag{3}$$

where:

g_{el}	the overall efficiency of supply of electricity
g_{fuel}	the overall efficiency of supply of fuels
$m_{fuel}^{prim} \cdot H_u^{prim}$	the energy of the primary energy carrier
W_{el}	the supplied electricity
$m_{fuel} \cdot H_u$	the supplied energy of fuel and
$CED_{plant,i}$	the Cumulative Energy Demand for installing, running and disposing of machines, plants and consumables providing the electricity or the fuel

The dimensionless overall efficiency of supply characterises, like an effectiveness, the efficiency of an energy supply from the deposit of a primary energy carrier up to the supply of final energy, respecting all energy demands.

1.3 The procedure of determining the CED using the process chain analysis

The CED of a product can be determined using economic statistics (input-output-tables of the energy input-output-analysis) or by means of a detailed process chain analysis. The energy input-output-analysis is suitable to calculate usable values for the CED of mass products with little effort. However, it shows methodological disadvantages concerning goods which are only produced in small numbers. Additionally, the high aggregation of input-output-tables does not allow a detailed analysis of the quantities causing the CED.

In contrast, the process chain analysis is well suited to produce detailed, precise and transparent results. A disadvantage is the considerable work caused by this method. The approach to determine the CED using the process chain analysis is shown below.

I Set-up of the process chain
II Selection of relevant processes and definition of cut-off criteria
III Balancing of the processes (inventory analysis)
IV Determination of primary energy
  IV.I Determination of the primary energy demands for raw materials, auxiliary materials and consumables as well as equipment of all processes
  IV.II Determination of the primary energy for the supply of final energy
V Calculation of the CED demand as a sum of all primary energy inputs

In Fig. 2, the diagram shows the material and energy flows which have to be analysed in order to determine the CED of any process.

For some frequently used materials (e.g. metal, synthetic materials, glass, concrete), detailed examinations concern-

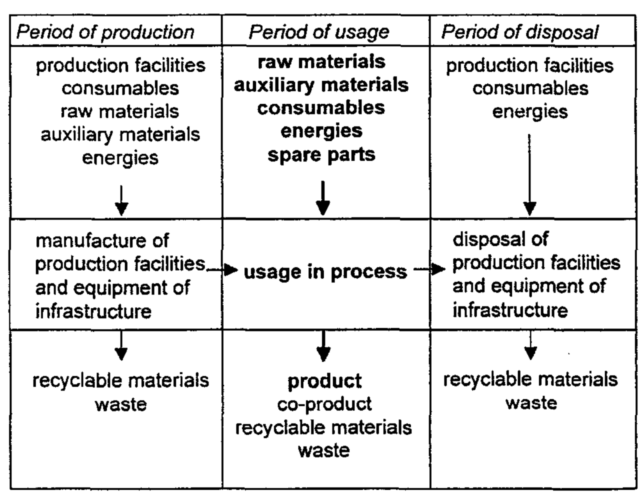

Fig. 2: Flow diagram of an inventory analysis of a process to determine the CED

ing the CED on the level of semi-finished products have been carried out by different authors. For many products, the energy demand for the production of a final product from a semi-finished one can be neglected regarding the energy demand of the production of a semi-finished product. Thus, within the process chain analysis, it is often sufficient to use corresponding values of semi-finished products which can be found in literature.

Summing-up all primary energies finally leads to the CED which can be assigned to an amount, a mass or another functional parameter of the product.

2 Application of the CED Method to Lignite Extraction

2.1 The opencast mine

In this paper, the extraction of lignite in an opencast mine in western Germany is examined. Overburden and lignite are mined continuously by bucket-wheel excavators. The material is transported around the pit by a conveyor system to a central belt junction where it is spread by conveyors to the stockpile or the overburden spreaders.

2.2 The mining process

In order to examine all processes which are necessary for the mining of lignite, a (local) point, which experiences all stages of the mining process, is regarded. Considering this, the process chain for an opencast mine is shown in **Fig. 3**.

In the first step, buildings, infrastructure, or installations and vegetation have to be removed. Then topsoil and overburden are mined selectively by bucket-wheel excavators, transported continuously by the conveyor system and stacked by overburden spreaders. When the seam is uncovered, the lignite is extracted by bucket-wheel excavators and conveyed to a loading point where it is passed to a hauling system for transportation to customers. The transportation to customers is not taken into account (cf. boundaries of examination in Fig. 3).

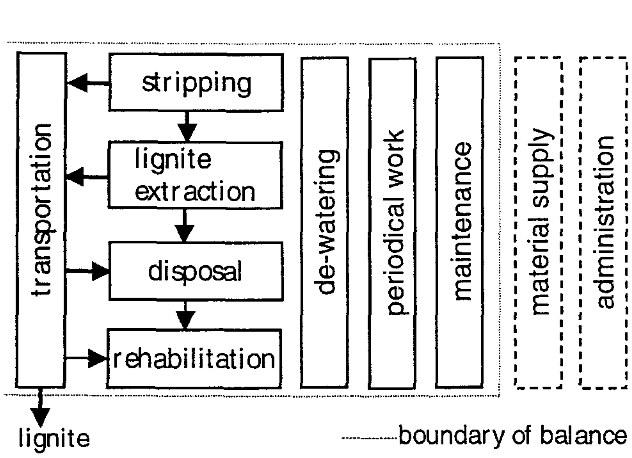

Fig. 3: Macro process chain for an opencast mine

3 Balancing of Lignite Mining

For the opencast lignite mine examined, it was possible to collate the consumption of fuels and electricity for one year [2]. In this case, 45.3 kWh of electricity per metric ton of lignite were used for running the equipment and to supply different general electrical consumption. A detailed distribution of the electricity demand of the included processes is shown in **Fig. 4**.

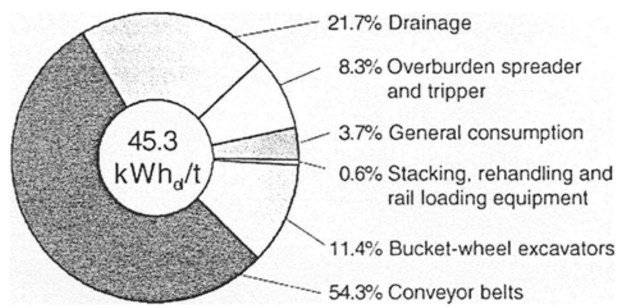

Fig. 4: Distribution of electricity demand to the processes of lignite mining

Due to the large conveyor system of the analysed opencast mine, the electrical demand is mainly influenced by the transportation of lignite, and especially of overburden (relation overburden – lignite: 8.6:1 m^3/t), and less by the consumption of the extraction equipment. Thus, 74% of all applied electricity refers to the mining and transportation equipment. The electricity consumption for drainage (21.7%) is the next relevant contribution. Other separately realised processes play only minor roles concerning the electricity consumption.

As the conveyor system is powered by electricity, the consumption of fuels (diesel) in the analysed opencast mine is relatively low (0.14 l/t_{lign}). **Fig. 5** shows a rough distribution of the fuel demand for the operation of auxiliary devices, motor vehicles and drainage processes.

The auxiliary devices include machines for surface preparation during the development phase and for the rehabilitation after mining or which are applied as mobile sprinkling devices for dust reduction.

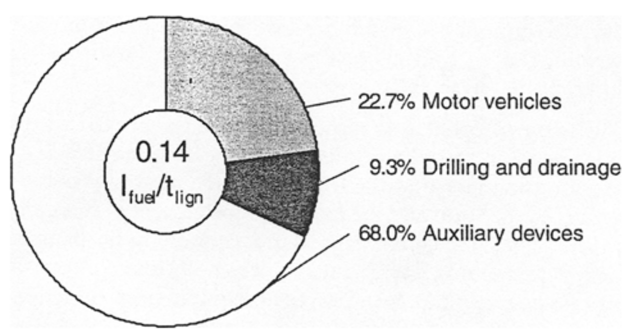

Fig. 5: Distribution of fuels for the operation of auxiliary devices, motor vehicles and drainage processes

4 Determination of Primary Energy Demand

For the primary energy assessment of the final energy inputs (see above), the Overall Efficiencies of Supply, listed in Table 1, are used. They characteristically describe the supply of electricity and fuel-oil in Germany. [1]

Within the calculations of the primary energy, the energy demands for production as well as for the use (especially maintenance or spare parts) and disposal of mining equipment are taken into account. The disposal of the employed equipment has only a subordinate share of the total energy demand and does not have to be taken into account because of its long utilisation period.

Table 1: Overall efficiency of supply for the calculation of primary energy in Germany

	Overall efficiency of supply	Annotations
fuel	0.88	
electricity	0.325	electricity mix Germany 1995: 55.8% coal, 28.9% nuclear, 8.1% gas, 3.7% hydro, 1.7% oil, 1.8% others

The energy demand for the provision of mining equipment has been determined using the masses of steel, copper and rubber. The relevant period of utilisation relative to 1 metric ton of mined lignite in the time period were taken into account. Values from literature are used, such as the CED of steel (28 GJ/t [4]), copper wire (100 GJ/t estimated by [4]), an estimate concerning the CED for rubber (96 GJ/t, balanced for the production of butadiene-elastomer [5] and our own calculations) and some different, estimated supplements for manufacturing. Furthermore, the energy demand for the supply of auxiliary devices is determined, assuming that sheet steel (33 GJ/t [4]) is used.

5 Results

In Table 2, concerning the mining equipment in the opencast mine, the CED of the production relative to 1t of lignite is summed up. This also includes material demands for the replacement of essential parts of the conveyor system. The calculation is based on the estimated working life of individual components, producer information and company experiences, as well as on the values in the literature for different materials.

The conveyor system is responsible for a great part of the energy demand for the production of the equipment. This is based on the fact that the life-time of the conveyor belts is limited by attrition and the frequent replacement of this component. Thus, the conveyor system turned out to be the most energy consuming part, as it requires both much electrical process energy and expenditures for equipment production.

Table 2: CED for the production of mining equipment in the opencast mine

Mining equipment	CED [MJ/t_{Lign}]	percentage [%]
Conveyor system	20.7	79.1
Bucket-wheel excavator	3.0	11.3
Overburden spreader and tripper	1.4	5.4
Drilling and drainage	0.4	1.6
Auxiliary devices	0.4	1.4
Stacking, rehandling and rail loading equipment	0.3	1.2
Total	26.2	100

The distribution of the assessed primary energy of the final energy demand (electricity and fuel), as well as the energy demand concerning the production of mining equipment, are shown in Fig. 6.

The high electricity demand of an opencast mine and the considerable primary energy demand for the supply of electricity are reflected in the share of 94% of the total primary energy demand. Furthermore, in the analysed opencast mine it is more important to determine the primary energy demand for the production of the equipment than for the consumption of fuel.

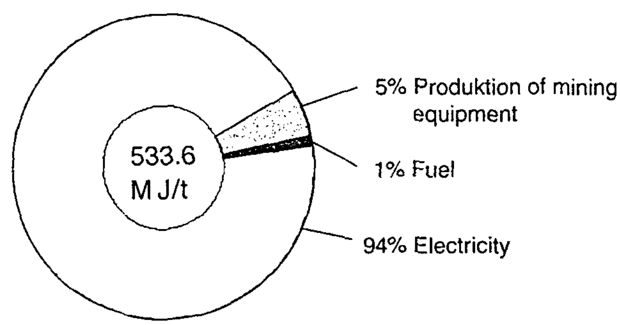

Fig. 6: Distribution of Cumulative (primary) Energy Demands of an opencast lignite mine

With reference to the energy content of lignite (net calorific value 8540 MJ/t [6]), the share of the primary energy demand for its extraction amounts to about 6.2%. This means that 93.8% of the lignite energy content is available as usable energy for further processes.

Our results of CED in opencast lignite mining in West-Germany obviously shows greater values than that seen in published data to date (Table 3). It seems to be that other studies have not considered the great electricity demand in lignite mining sufficiently.

Owing to favourable geological conditions, the CED in lignite extraction in East-Germany ranges between 90 and 160 MJ/t. So the share of primary energy demand for lignite mining amounts to only 0.8% to 1.8% [6,7,8].

[1] The Overall efficiency of supply for the electricity from lignite power stations, normally supplying the opencasts, is shown by the overall efficiency of supply for the electricity mix as estimated in Germany.

Table 3: Results of different studies about CED of lignite mining in West-Germany

	CED [MJ/t_{Lign}]	prim. energy demand for extraction [%]
this study	533.6	6.2
GaBi 3.0 (Germany)	459.6	4.9
GEMIS 3.x	281.8	3.3
GEMIS 3.x [a)]	310.6	3.5
IfE TU-Muenchen	357 [b)]	4.18

[a)] Source: German Electricity Association (VDEW)
[b)] estimated with a net calorific value of 8540 MJ/t

6 Conclusion

Within an entire energy assessment of the utilisation of lignite as an energy carrier, the energy demanded for the supply of energy carriers must also be respected. Due to the predominantly West-German lignite mining in Germany (about 60%), the great CED of 533.6 MJ/t in Rhenish-area has to be considered.

Caused by different geological circumstances and frequently varying mining conditions, the results of this analysis cannot be transferred simply to other mines or operating years. It has to be checked whether boundary conditions, especially the relation between overburden and water to lignite or the supply of the mining equipment with electricity or fuel, allow a transfer of the determined values.

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